



EDUCATOR EDITION *AP Physics*

SPACE EXPLORATION AP



LUNAR LANDING

Instructional Objectives

Students will

- choose a coordinate system best suited to the problem;
- apply equations of motion and force to solve for unknowns;
- determine magnitude and direction of vectors; and
- calculate a spring constant.

Degree of Difficulty

This problem is a straightforward application of the equations of motion and force.

- For the average AP Physics student, the problem may be moderately difficult.

Background

This problem is part of a series of problems that apply physics principles to NASA's Vision for Space Exploration.

Exploration provides the foundation of our knowledge, technology, resources, and inspiration. It seeks answers to fundamental questions about our existence, responds to recent discoveries and puts in place revolutionary techniques and capabilities to inspire our nation, the world, and the next generation. Through NASA, we touch the unknown, we learn and we understand. As we take our first steps toward sustaining a human presence in the solar system, we can look forward to far-off visions of the past becoming realities of the future.

The Vision for Space Exploration includes returning the space shuttle safely to flight, completing the International Space Station, developing a new exploration vehicle and all the systems needed for embarking on extended missions to the Moon, Mars, and beyond.

A new era of NASA space exploration began on July 20, 1969 with the Apollo 11 mission. That year the lunar module Eagle landed on the surface of the Moon (Figure 1). Landing on the Moon was an important step towards future space exploration and it was one that was viewed by the world. It is estimated that one billion people world-wide watched Neil Armstrong's first step onto the surface of the Moon and heard him say the words, "That's one small step for man, one giant leap for mankind!"

Supplemental Problem for AP Physics

Grade Level
11-12

Key Topic
Equations of Motion and Force

Degree of Difficulty
Basic to Moderate

Teacher Prep Time
5 minutes

Problem Duration
15-20 minutes

Technology
Calculator

Materials
Student Edition including:
- Background handout
- Problem worksheet

NSES
Science Standards
- Physical Science
- History and Nature of Science

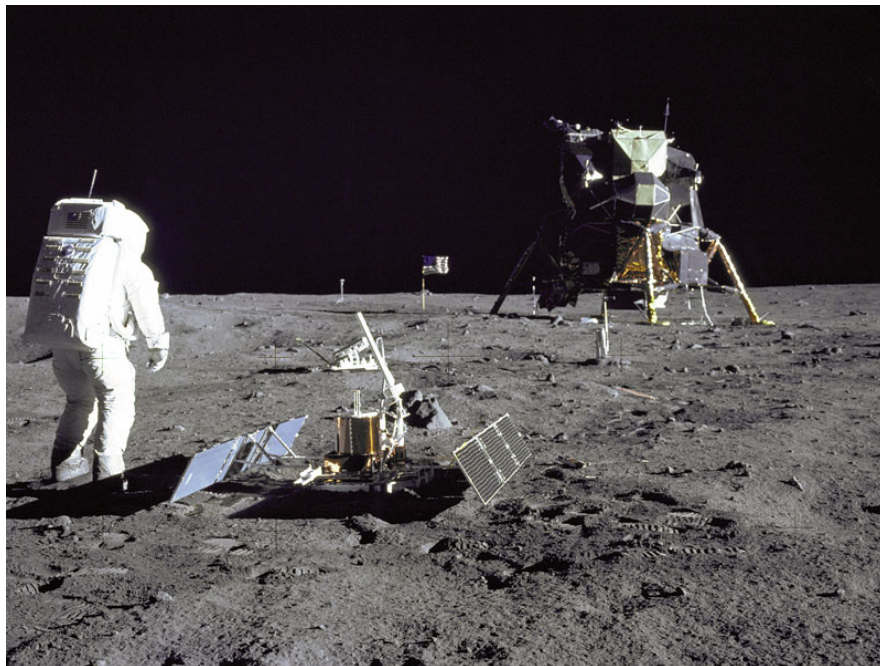


Figure 1: Apollo 11 Lunar Module

Since that time, tremendous strides have been made in science and technology, with developments continuing to advance. Space exploration is on the forefront of this progress. NASA's current plan is to send humans back to the surface of the Moon then on to extended missions. NASA astronauts will again explore the Moon and this time, they're going to stay! Technological advances will allow astronauts to build outposts, conduct new research, and learn to live on a surface different from Earth's. This will pave the way for eventual journeys to Mars and beyond.

The human exploration missions to the Moon that took place during the Apollo program and the robotic exploration missions of the Ranger, Surveyor, and Lunar Orbiter programs that preceded the Apollo astronauts, returned a wealth of information that helped develop a new scientific understanding of the Moon. After Apollo, additional scientific knowledge about the Moon was gained from the Clementine, Lunar Prospector and SMART-1 missions - all robotic spacecraft that explored the Moon from lunar orbit. Based on the information gathered from all of these past missions, scientists and engineers have proposed future landing sites that could provide clues to still unanswered questions about the Moon.

The proposed landing sites will bring us to locations where potential resources may be located. Hydrogen will probably be found in the form of water ice in permanently shadowed craters near the lunar polar region. Another chemical element that may be found in some of the potential landing sites is oxygen, probably bound in the crystalline minerals of the lunar soil.

Although it's been done before, landing spacecraft on the lunar surface is not easy. The Moon's gravitational force is 0.165 times the surface gravity on Earth. This difference in surface gravity affects the amount of thrust, or opposing gravitational force, needed to land. Another critical decision for landing on the lunar surface is the landing location. Landing safely means avoiding rocks, holes or slopes large enough to damage the spacecraft. This is called hazard avoidance. Selecting landing sites that will be advantageous and interesting for science and engineering is also important.

On Apollo missions, the crew looked out the window and visually picked a safe landing location. When NASA returns crews to the Moon, the astronauts will use new hazard avoidance technologies with



sensors to help the crews land safely on the lunar surface. On unpiloted missions, the spacecraft will have systems on board to automatically find the safe areas and land the spacecraft. NASA's latest development projects, including the new Lunar Lander (Figure 2) with hazard avoidance technology, will enable astronauts to safely land and explore the surface of the Moon.

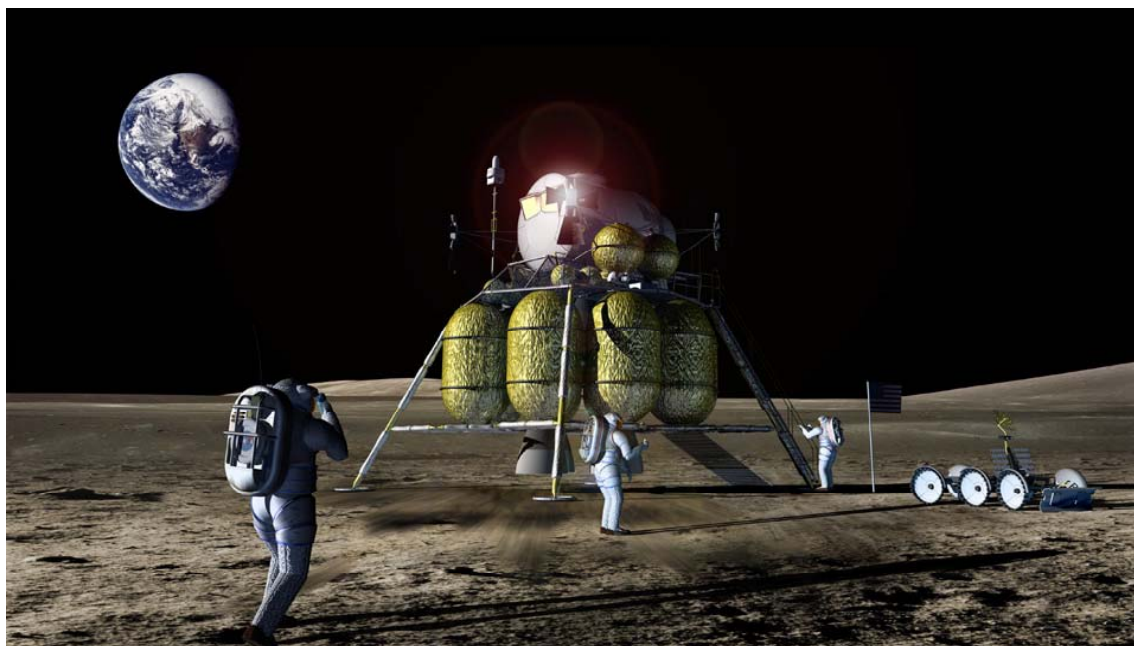


Figure 2: Lunar Lander (NASA concept)

Landing safely and learning to live on the Moon will give NASA a head start in exploring Mars and other destinations in the solar system. A lunar outpost just three days away from Earth will offer needed practice of "living off the land" away from our home planet, before making the longer treks further out into the solar system.

For more information about landing on the Moon and the Vision for Space Exploration, visit www.nasa.gov.

NSES Science Standards

Physical Science

Motion and Forces

- Objects change their motion only when a net force is applied. Laws of motion are used to calculate precisely the effects of forces on the motion of objects.

History and Nature of Science

Science as a Human Endeavour

- Individuals and teams have contributed and will continue to contribute to the scientific enterprise.
- Scientists are influenced by societal, cultural, and personal beliefs and ways of viewing the world. Science is not separate from society but rather science is a part of society.



Historical Perspective

- The daily work of science and engineering results in incremental advances in our understanding of the world and our ability to meet human needs and aspirations. Much can be learned about the internal workings of science and the nature of science from study of individual scientists, their daily work, and their efforts to advance scientific knowledge in their area of study.

Problem

During a lunar landing the spacecraft is 100 meters above the lunar surface and coming straight down to a safe landing location with a constant thrust. The velocity of the spacecraft is 10 meters per second (m/s) at this point. The lander should touch down on the surface at 0.5 m/s due to the constant thrust (Figure 3).

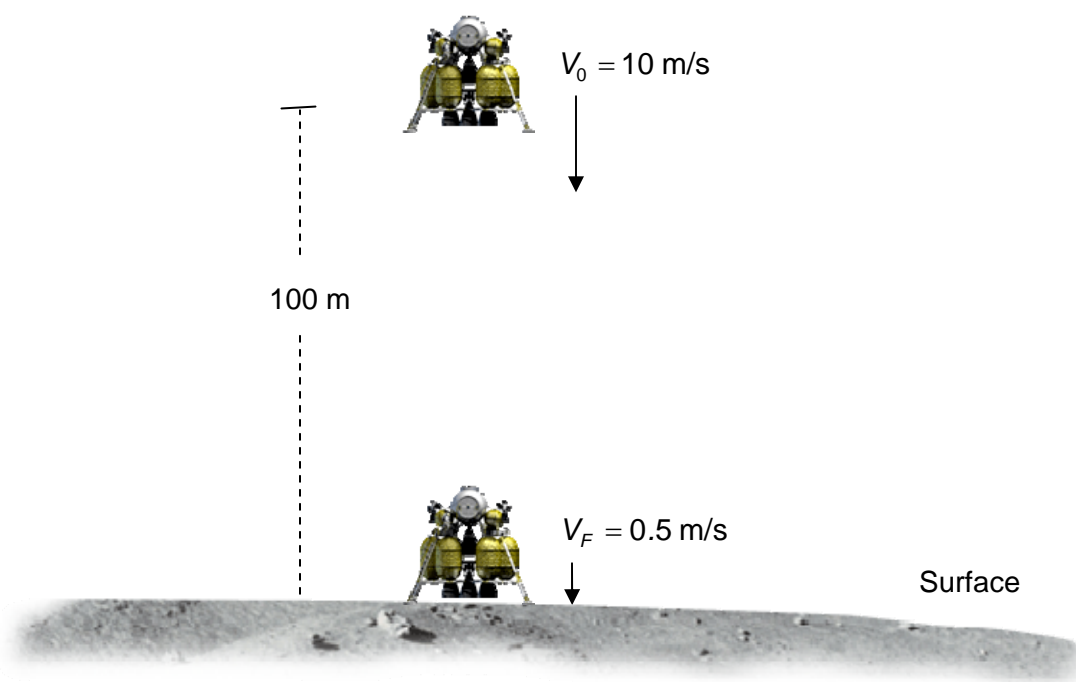


Figure 3: Problem Diagram

- What is the magnitude and direction of the acceleration of the spacecraft? Express your answer in m/s^2 .
- How long does it take to reach the surface from 100 m?
- If the spacecraft has a mass of 20,000 kilograms (kg), what thrust in newtons must the engines be exerting? Ignore the change in mass of the spacecraft due to propellant use.



4. In NASA's current concept, the lander has 4 legs, each with a plate on the end that will set firmly on the surface. Each leg has a spring to act as a shock absorber and each shock will compress 30 cm when the leg plates touch the surface at a velocity of 0.5 m/s. Assume the engines' thrust goes instantly to zero at the time of contact with the surface and the lunar surface does not compress. What is the average acceleration of the vehicle after it touches the surface? What is the spring constant for each spring?

Solution Key (One Approach)

1. What is the magnitude and direction of the acceleration of the spacecraft? Express your answer in m/s^2 .

Since the force (thrust) is constant the acceleration is constant so we can use the equations for constant acceleration. Let's place the origin of our measurement system at the point of impact with up being positive and down being negative.

$$v_f^2 - v_i^2 = 2as$$

$$a = \frac{v_f^2 - v_i^2}{2s}$$

$$a = \frac{(-0.5 \text{ m/s})^2 - (-10 \text{ m/s})^2}{2(-100 \text{ m})}$$

$$a = 0.499 \text{ m/s}^2$$

Acceleration is positive and thus up.

Note that the displacement, s , is really the final position minus the original position.
 $0 \text{ m} - 100 \text{ m} = -100 \text{ m}$ symbolizing the vehicle traveling 100 m down.

2. How long does it take to reach the surface from 100 m?

$$v_f = v_i + at$$

$$t = \frac{v_f - v_i}{a}$$

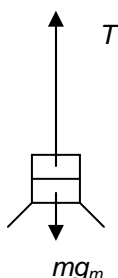
$$t = \frac{-0.5 \text{ m/s} - (-10 \text{ m/s})}{0.499 \text{ m/s}^2}$$

$$t = 19.038 \text{ seconds}$$



3. If the spacecraft has a mass of 20,000 kilograms (kg), what thrust in newtons (N) must the engines be exerting? Ignore the change in mass of the spacecraft due to propellant use.

The spacecraft has two forces working on it. The thrust (T), which we are trying to find and the force caused by the Moon's gravitational pull (mg_m). The total force (F) on the spacecraft is then $T - mg_m$. This takes into account the direction of g_m .



$$F = ma$$

$$T - mg_m = ma$$

$$T = ma + mg_m$$

$$T = m(a + g_m)$$

$$T = 20,000 \text{ kg} [0.499 \text{ m/s}^2 + (0.165)(9.8 \text{ m/s}^2)]$$

$$T = 42,320 \text{ N}$$

4. In NASA's current concept, the lander has 4 legs, each with a plate on the end that will set firmly on the surface. Each leg has a spring to act as a shock absorber and each shock will compress 30 cm when the leg plates touch the surface at a velocity of 0.5 m/s. Assume the engines' thrust goes instantly to zero at the time of contact with the surface and the lunar surface does not compress. What is the average acceleration of the vehicle after it touches the surface? What is the spring constant for each spring?

Step 1: Find the average acceleration.

$$a = \frac{v_f^2 - v_i^2}{2s}$$

$$a = \frac{(0.0 \text{ m/s})^2 - (-0.5 \text{ m/s})^2}{2(-0.3 \text{ m})}$$

$$a = 0.417 \text{ m/s}^2$$

Step 2: Find the force on each leg.

$$F_4 = 20,000 \text{ kg}(0.417 \text{ m/s}^2)$$

$$F_4 = 8,340 \text{ N}$$

This is total force so each leg exerts 2,085 N



Step 3: Find the spring constant for each spring.

$$F = -kx$$

$$k = -\frac{F}{x}$$

$$k = -\frac{2085 \text{ N}}{-0.3 \text{ m}}$$

$$k = 6,950 \text{ N/m}$$

The springs should be well damped so the vehicle doesn't oscillate.



Contributors

Thanks to the subject matter experts for their contributions in developing this problem:

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